TECH460 Final Project: IoT Environmental Monitoring Pilot for BESS Inverter Maintenance Optimization

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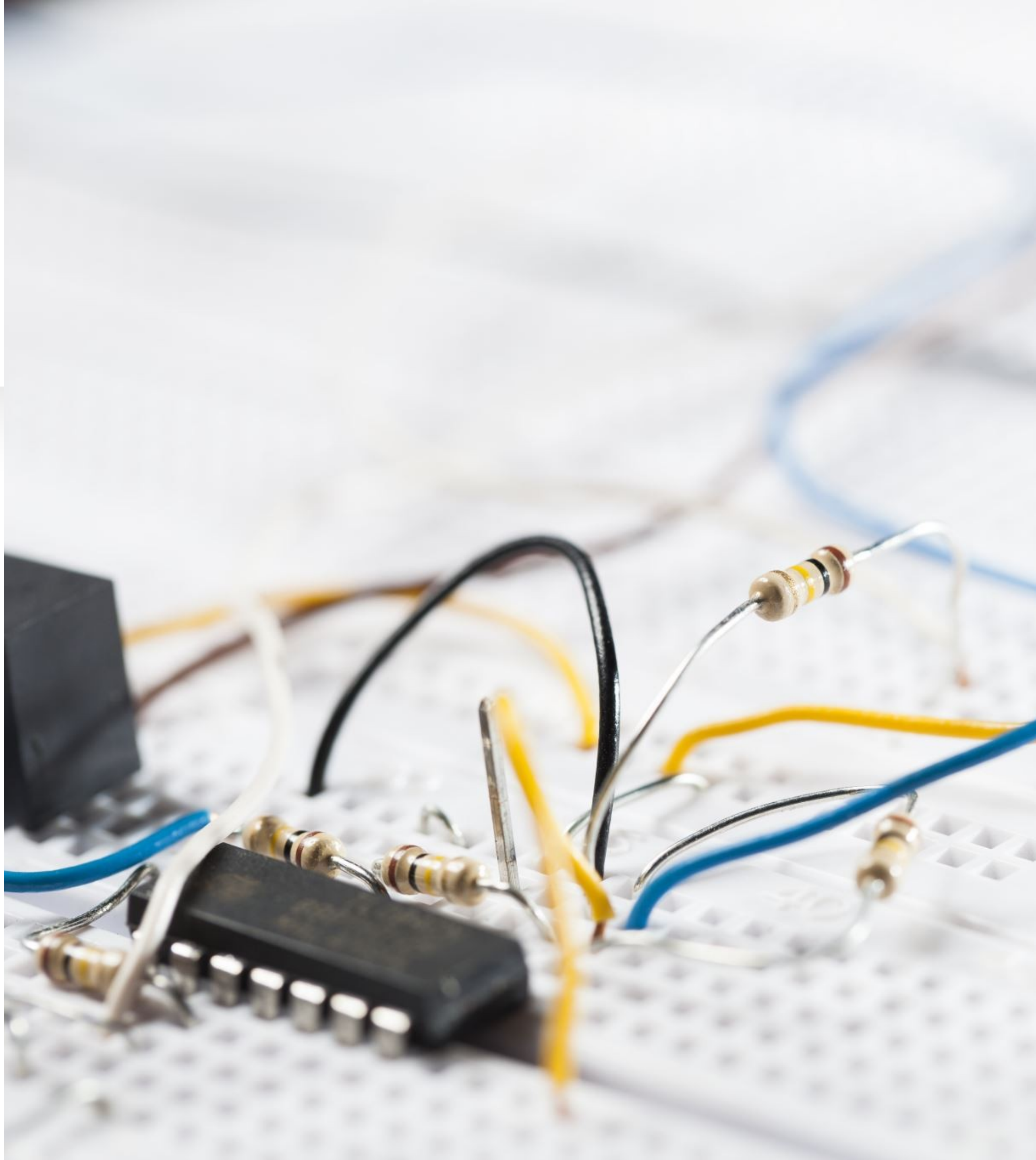
Introduction

- This capstone project proposes a research-driven pilot study to investigate whether environmental monitoring can improve maintenance operations for Power Electronics inverters in Battery Energy Storage System (BESS) installations.

- The project adopts a staged scientific approach:
- Hypothesis Development: Can environmental data predict equipment degradation?
- Data Collection: 12-month pilot on 5 inverters
- Analysis: Statistical validation of correlations
- Recommendations: Scale or pivot based on evidence

- Rather than assuming ROI, this research pilot will gather actual data to determine if the hypothesis is valid before recommending portfolio-wide deployment.



Executive Summary

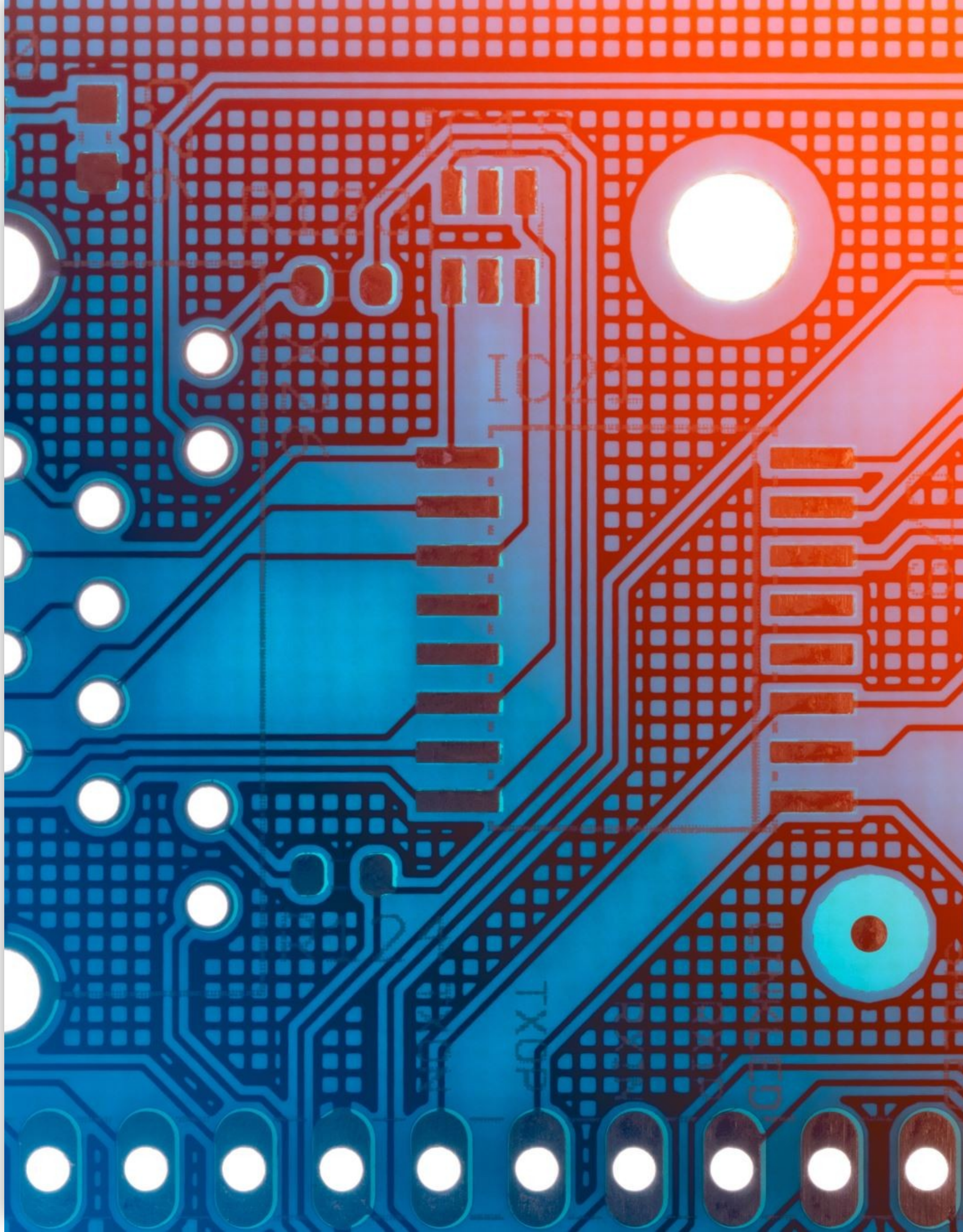
- Problem: Power Electronics inverters in desert climate BESS installations experience cooling system failures due to dust accumulation. Current reactive maintenance is inefficient.

- Research Question: Can we prove that environmental factors (dust, airflow, temperature) have measurable, predictable effects on equipment performance?

- Proposed Solution: 12-month data collection pilot on 5 inverters to test hypothesis and establish evidence-based maintenance protocols.

- Investment: $13,400-$15,650 for pilot study

- Expected Outcome: Validated data proving (or disproving) correlation between environmental conditions and equipment degradation, enabling informed decision on scaling approach.



Organization Profile and Problem Statement

Academic Disclosure: Fictional Company Name

Professional Ethics Notice: While the technical problems, solutions, and industry analysis presented in this project are based on real-world battery energy storage system challenges, "The BESS Company" is a fictional organization name used for academic purposes.

Rationale: As a professional working in the energy storage industry, using my actual employer's name in an academic context that discusses operational challenges and improvement opportunities could create conflicts of interest, violate confidentiality agreements, or misrepresent internal company positions to external entities.

Technical Validity: The Power Electronics inverter ventilation issues, IoT solutions, and industry analysis presented are based on legitimate technical knowledge and publicly available information about battery energy storage systems, ensuring this project maintains academic and technical integrity while respecting professional boundaries.

The Organization: The BESS Company

The BESS Company is a global market leader in battery energy storage systems (BESS), specializing in utility-scale energy storage solutions. The company has deployed numerous energy storage assets globally, making it one of the top utility-scale energy storage integrators in the market.

Key Facts:

- Private Company
- 600+ employees globally
- Operations in 30+ countries

Market Position:

- Experienced engineering team
- Strong safety record
- Tier 1 BESS provider

Products and Services

Software & Services:

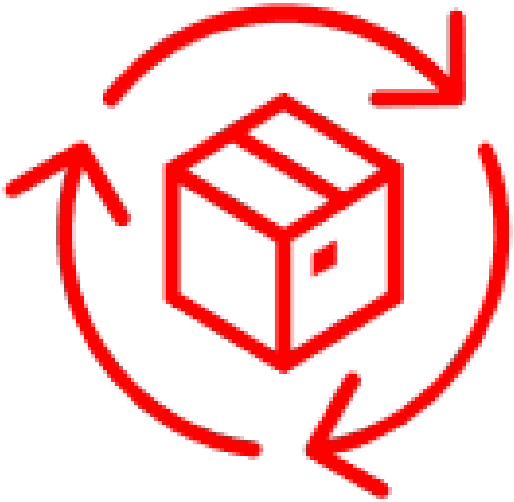
StorageIQ Platform: AI-powered digital intelligence for asset management

MarketOptimizer: Automated bidding and revenue optimization software

PerformanceMonitor: Asset performance management and predictive maintenance

Hardware Products:

- PowerCell Pro: Utility-scale battery storage systems for grid applications
- EnergyMax HD: High-density energy storage platform for space-constrained installations
- GridForte: Transmission-grade energy storage for critical infrastructure



Service Offerings:

The BESS Company provides engineering and construction services including project development, system integration, and turnkey delivery solutions. Their operations and maintenance portfolio includes long-term service agreements, remote monitoring capabilities, and performance guarantees. The company also offers digital solutions focused on revenue optimization, predictive analytics, and grid integration services to maximize asset value and operational efficiency.

Areas for Improvement with Technology

Power Electronics Inverter Issues:

- Inverter overheating problems
- Ventilation system inefficiencies
- Cooling system blockages
- Frequent fan failures due to filter clogging

Battery Management Issues:

- Cell imbalance problems
- Manual maintenance requirements
- Limited real-time fault detection
- Reactive maintenance approach

Problem Statement / Hypothesis

What We Know:

Desert environments cause dust accumulation in Power Electronics inverter cooling systems

Air filters get dirty and reduce cooling efficiency over time

Current maintenance follows a preventative schedule, but it's kind of blind, by the time we get around to it, we practically have a desert inside the modules

Research Question:

Can we prove a correlation exists between environmental conditions and cooling system performance degradation?

Our Hypothesis:

By systematically recording environmental data (dust, airflow, temperature), we can optimize O&M cycles

Environmental factors have measurable, predictable effects on equipment performance

This data could make our maintenance teams more efficient in predictive, preventive, and corrective maintenance

Technology Selection and Design

Alternative Technology Approaches

Alternative 1: Direct Environmental Monitoring System

Technology: Multi-parameter environmental sensors (dust, airflow, temperature, humidity)

Operation: Laser-based particle detection + differential pressure + precision temperature sensing

Data Output: Complete environmental picture of cooling system conditions

Approach: Measure the actual environmental factors affecting equipment

Alternative 2: Indirect Mechanical Monitoring System

Technology: Mechanical condition monitoring (filter pressure, fan vibration, temperature)

Operation: Differential pressure sensors + accelerometers + temperature probes

Data Output: Equipment health indicators and mechanical performance metrics

Approach: Monitor symptoms of environmental impact rather than root causes

Qualitative Analysis

Criteria	Alternative 1: Environmental	Alternative 2: Mechanical	Winner
Data Relevance for Hypothesis	Directly measures environmental causes (dust, airflow degradation)	Measures mechanical symptoms (filter loading, fan stress)	Alternative 1
Implementation Complexity	Moderate - requires environmental sensor integration	Low - standard industrial sensors	Alternative 2
Predictive Capability	High - can predict cooling degradation before failure	Medium - reactive to mechanical changes	Alternative 1
Research Value	Tests root cause hypothesis directly	Limited to mechanical correlation	Alternative 1
Availability	Commercial IoT sensors available	Standard industrial sensors	Tie

Quantitative Analysis		
12-Month Pilot Project Costs (Instrumenting 5 Existing Inverters)		
Cost Component	Alternative 1: Environmental	Alternative 2: Mechanical
Sensor Hardware (35 sensors)	$1,600 (rental/lease)	$2,500
Power Infrastructure (5 units)	$3,300 - $5,550	$3,300
Communication Infrastructure	$2,000	$1,500
Cloud Platform & Analytics (12 months)	$1,500	$1,000
Data Analysis & Reporting	$3,000	$2,500
Project Management	$2,000	$1,500
Total Pilot Investment	$13,400 - $15,650	$12,300
Expected Data Collection		
130,000+ measurements over 12 months		
Research Goal: Prove correlation between environmental factors and performance		
Success Metric: Can we predict cooling system degradation from environmental data?		

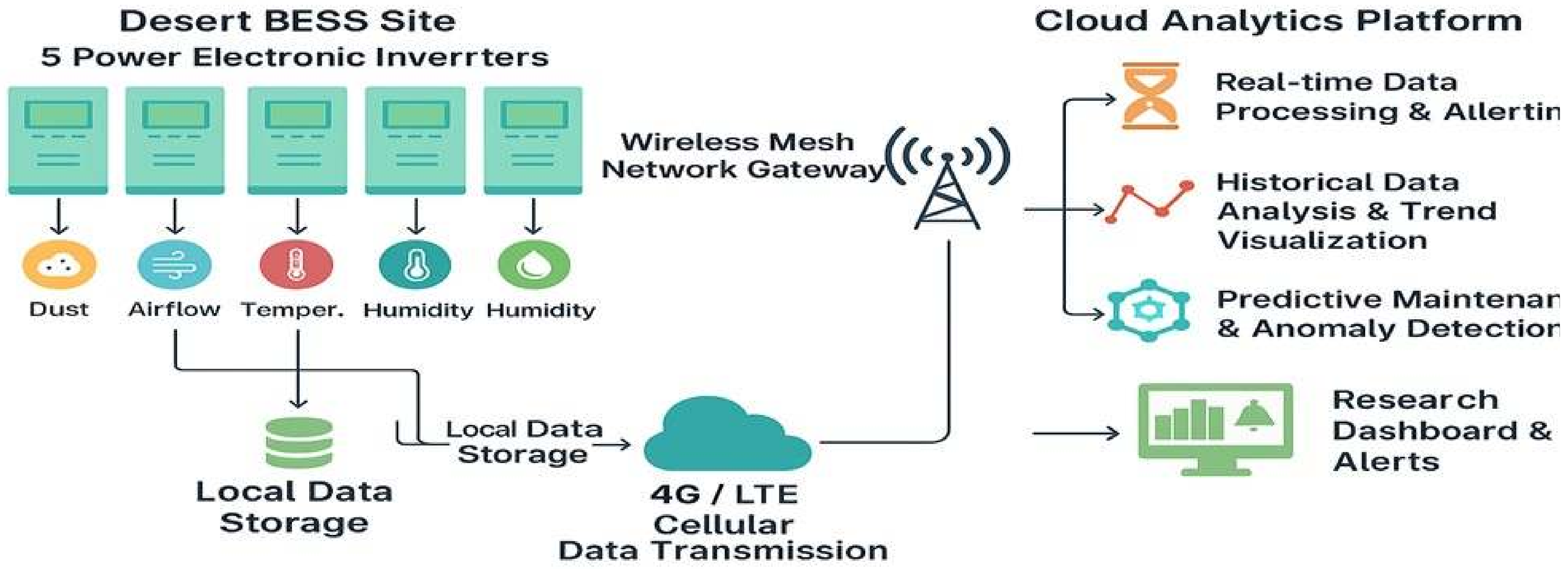
Recommended Solution

Selected Approach: Direct Environmental Monitoring System (Alternative 1)

Why This Choice Makes Sense:
Tests Our Hypothesis Directly: Measures the actual environmental causes we think are driving performance issues
Better Research Data: Environmental patterns give us predictive capability rather than just reactive indicators
Manageable Pilot Scale: 5 inverters with 35 sensors = realistic data collection project
Reasonable Investment: $13K-$16K to test a theory is justifiable research expense
Clear Success Criteria: Either we can correlate environmental data to performance, or we can't

The Research Approach:
Stage 1: Run this 12-month pilot on 5 inverters
Stage 2: Analyze data for measurable correlations
Stage 3: If hypothesis is validated, justify scaling to more units
Stage 4: If data doesn't support theory, pivot to different approach

Pilot Deployment Architecture



Research Questions:

- Does dust buildup predict temperature rises?
- Can we see airflow reduction before overheating?
- What's the optimal cleaning interval?
- Are there seasonal patterns?
- Can we predict failures 2-4 weeks early?

Data Collection:

- Dust concentration (4 particle sizes)
- Airflow velocity changes
- Temperature trends
- Equipment performance metrics
- Maintenance event timing

Success Definition:

If we can demonstrate measurable correlations between environmental conditions and equipment performance degradation, then we've validated our hypothesis and can justify scaling the approach across more inverters in the fleet.

What We'll Measure vs. What We Hope to Learn

Implementation Plan

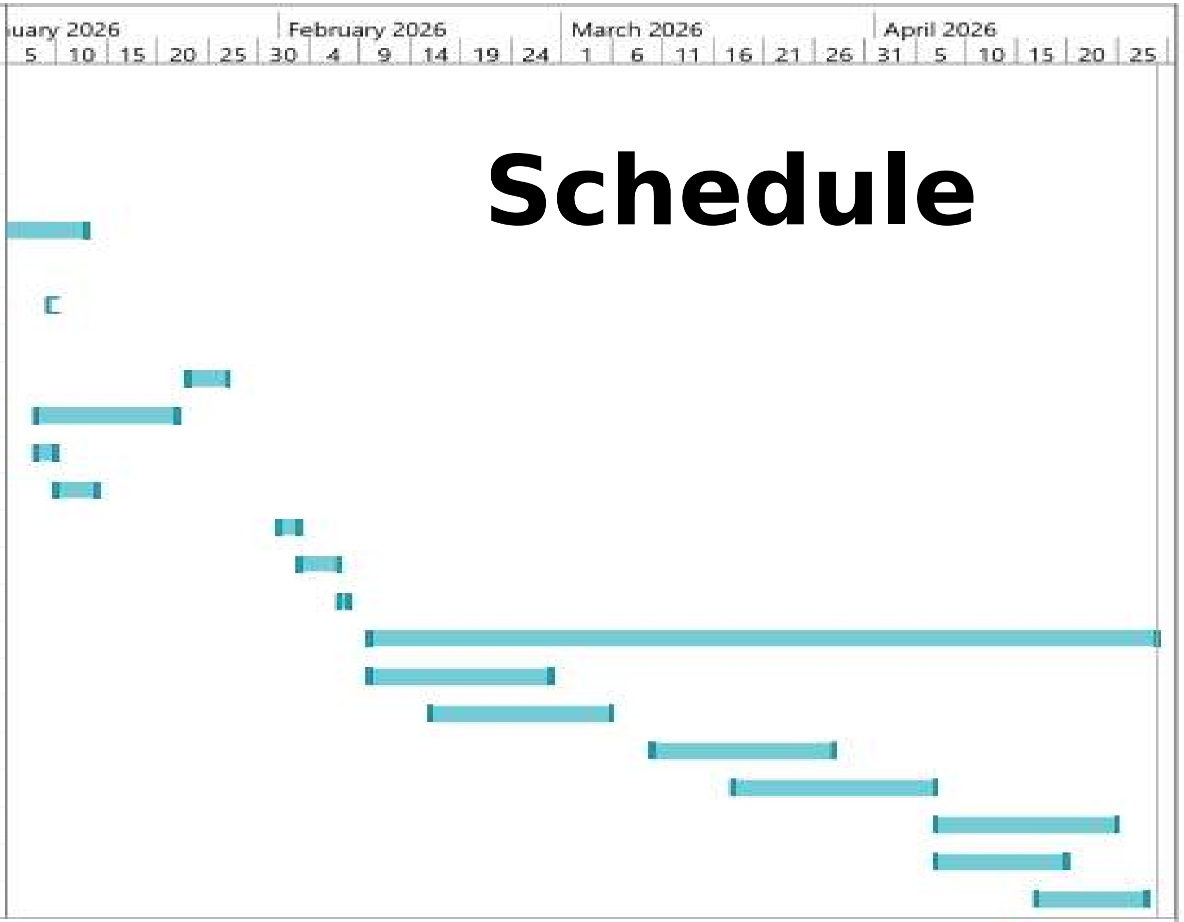
Work Breakdown Structure

Phase 1: Planning & Setup (21 days)
Site assessment and sensor planning
Review Power Electronics manuals
Develop safety procedures
Procure sensors and equipment
Setup cloud platform
Get Power Electronics OEM approval
Phase 2: Installation (10 days)
Mobilize and prepare site
Install first inverter (validation unit)
Test and validate first unit
Install remaining four inverters
System integration testing
Phase 3: Data Collection (56 days)
First quarter monitoring
Second quarter monitoring
Third quarter monitoring
Fourth quarter monitoring
Phase 4: Analysis & Reporting (14 days)
Statistical analysis and hypothesis testing
Write report and prepare presentation

Total: 22 tasks | Duration: 101 days (~3.5 mont

Schedule

ID	Task Mode	Task Name	Duration	Start	Finish
1		Task Name	Duration	Start	Predecessors
2		Phase 1: Planning & S	21 days	Fri 1/2/26	
3		Site assessment and s	5 days	Fri 1/2/26	
4		Review Power Electrc	5 days	Fri 1/2/26	
5		Develop safety proce	7 days	Fri 1/2/26	Mon 1/12/26
6		Procure sensors and	14 days	Fri 1/2/26	
7		Setup cloud platform	10 days	Fri 1/9/26	
8		Get Power Electronic	14 days	Fri 1/2/26	
9		Phase 1 completion r	2 days	Fri 1/23/26	Mon 1/26/26
10		Phase 2: Installation	10 days	Thu 1/8/26	Wed 1/21/26
11		Mobilize and prepare	2 days	Thu 1/8/26	Fri 1/9/26
12		Install first inverter (v	3 days	Sat 1/10/26	Tue 1/13/26
13		Test and validate first	2 days	Sun 2/1/26	Mon 2/2/26
14		Install remaining 4 in	4 days	Tue 2/3/26	Fri 2/6/26
15		System integration te	1 day	Sat 2/7/26	Sat 2/7/26
16		Phase 3: Data Collecti	56 days	Tue 2/10/26	Tue 4/28/26
17		First quarter monitori	14 days	Tue 2/10/26	Fri 2/27/26
18		Second quarter moni	14 days	Mon 2/16/26	Thu 3/5/26
19		Third quarter monito	14 days	Tue 3/10/26	Fri 3/27/26
20		Fourth quarter monit	14 days	Wed 3/18/26	Mon 4/6/26
21		Phase 4: Analysis & R	14 days	Tue 4/7/26	Fri 4/24/26
22		Statistical analysis	10 days	Tue 4/7/26	Sun 4/19/26
23		Write report and pres	7 days	Fri 4/17/26	Mon 4/27/26



Project: Project1
Date: Wed 10/8/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Validation

Validation → How the Solution Will Be Validated Before Deployment: → PreDeployment Testing (Week 1): → 1. Install sensors on first inverter only (validation unit) → • 7 environmental sensors per test unit → • Complete power and communication integration

→ 2. Accuracy Verification → • Compare sensor readings to calibrated handheld meters → • Verify measurements within ±10% specification → • Test all parameters: dust, airflow, temperature, humidity → 3. Reliability Testing → • Run validation unit continuously for 1 week

→ • Monitor data transmission every 15 minutes → • Track cloud platform data reception → 4. Data Quality Gate → • Requirement: >95% data capture rate → • If PASS proceed to full deployment (4 more inverters) → • If FAIL troubleshoot, adjust, and retest

→ 5. Full Deployment Authorization → • Apply lessons learned from validation → • Install remaining 28 sensors (4 inverters × 7 sensors) → • Begin data collection phase → Success Criteria: All 35 sensors operational with >95% uptime → before entering research data collection period.

Evaluation and Continuous Improvement

1. How the Solution Will Be Evaluated During Operation:
2. During 8Week Data Collection:
3. Weekly data quality checks
4. Are sensors still transmitting reliably?
5. Do readings show expected environmental patterns?
6. Biweekly preliminary analysis
7. Initial correlation patterns
8. Hypothesis validation progress tracking
9. Environmental pattern identification
10. Maintenance event correlation
11. Compare dust levels when cleaning happens
12. Document temperature trends before/after maintenance
13. Track airflow degradation timelines
14. Final Evaluation (Weeks 1113):
15. Statistical hypothesis testing
16. Does dust buildup predict temperature rise?
17. Can airflow reduction provide early warning?
18. What's the optimal cleaning interval?
19. Decision Framework
20. IF correlation proven: Recommend scaling to more inverters
21. correlation: Document findings, propose alternative
22. Continuous Improvement Path:
23. Refine sensor placement based on findings
24. Optimize alert thresholds from baseline data
25. Develop maintenance procedure recommendations
26. Either outcome advances knowledge and informs next steps

Legal, Ethical and Cultural Considerations

Legal Considerations:

Company confidentiality: Using 'The BESS Company' pseudonym to protect employer identity

OEM requirements: Power Electronics approval required for 24V auxiliary power access

Safety compliance: OSHA LOTO procedures (29 CFR 1910.333) for equipment up to 1500V DC

Warranty protection: All modifications documented and approved

Ethical Considerations:

Research integrity: Honest reporting whether hypothesis is validated or disproven

No confirmation bias: Report findings objectively, not selectively

Safety first: All equipment modifications properly documented

Transparent limitations: This is academic research with assumptions

Cultural Considerations:

Desert site operations: Respect for extreme heat work practices

Field technician knowledge: Their operational experience is valued

Learning posture: Graduate student as learner, not expert consultant

Collaborative approach: Cross-functional input from engineering, operations, IT, and safety

Realistic expectations: Field conditions may differ from theoretical plans

Incorporation of Feedback

Module 6 Peer Feedback (peer reviewer) - Summary and Response:

Strengths Noted:

Clear problem statement and well-defined hypothesis

Practical staged approach (pilot → analysis → scale-up)

Comprehensive attention to legal, ethical, and cultural considerations

Recommendations Received:

Add visual structure to help technical flow come through clearly

Use SmartArt and charts to enhance content-heavy slides

Add simple data flow diagrams for easier comprehension

Actions Taken to Improve Final Project:

Restructured project as research pilot with clear hypothesis testing framework

Emphasized staged approach: gather data first, then make scaling decisions

Clarified that ROI projections are assumption-based until pilot validates correlation

Added clearer success criteria tied to measurable correlations

Maintained comprehensive legal/ethical/cultural considerations

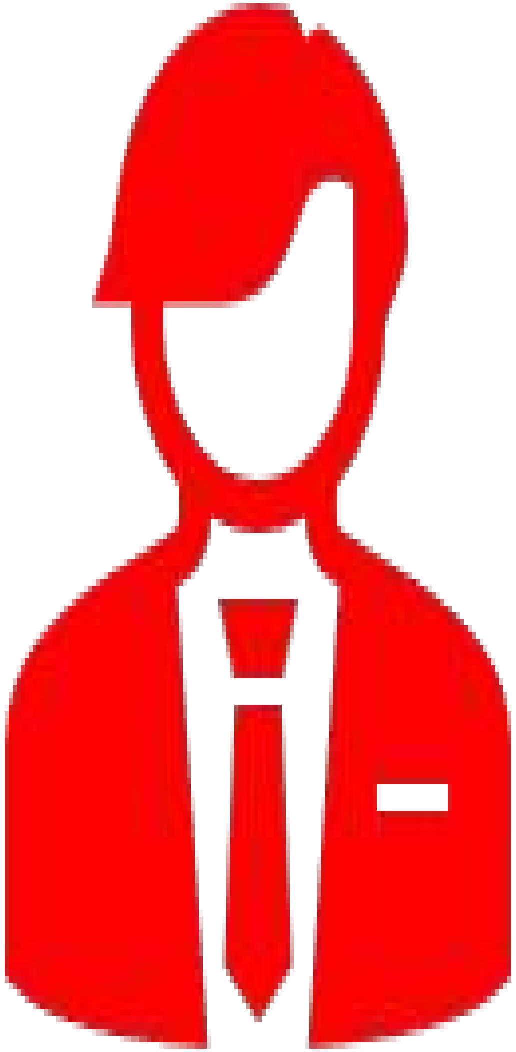
Simplified cost analysis to focus on pilot scale (5 inverters vs. 20)

Emphasized academic research methodology over implementation certainty

The feedback reinforced the importance of framing this as a research investigation to determine if environmental monitoring is worth pursuing, rather than assuming the solution will succeed.

Career Readiness

- How This Project Improved Career Readiness:
- Technical Skills Development:
- IoT sensor integration and industrial monitoring systems
- Data analysis and correlation methodology for predictive maintenance
- Project planning with Work Breakdown Structure and Gantt charts
- Risk assessment and stakeholder management in industrial environments
- Professional Growth:
- Applying scientific method to business problems
- Managing assumptions and uncertainty in ROI projections
- Cross-functional collaboration (engineering, operations, safety, IT)
- Balancing academic rigor with practical implementation constraints
- Career Application:
- Portfolio piece demonstrating research methodology and critical thinking
- Shows ability to structure complex pilot projects with measurable outcomes
- Evidence of ethical considerations and professional boundaries
- Demonstrates understanding of staged implementation and data-driven decision making
- Future Use:
- Template for proposing data collection pilots in professional settings
- Framework for hypothesis-driven operational improvement projects
- Example of academic-professional boundary management
- Foundation for potential conference presentation or industry publication on research methodology



Conclusion

This project proposed a research pilot, not a finished solution.

The Question:

- Can environmental data predict cooling system degradation in desert BESS inverters?
- Maintenance currently runs on a fixed schedule, not on site conditions.

The Proposal:

- Twelve-month pilot on five existing inverters, 35 environmental sensors.
- Total investment of $13,400 to $15,650.

What the Result Buys:

- A validated correlation justifies scaling predictive maintenance across the fleet.
- A disproven hypothesis rules out the approach before portfolio-wide spend.
- Either outcome replaces assumption with evidence.

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